



Sensing Strategies and Software Tools to Help Farmers Adapt to Climate Change

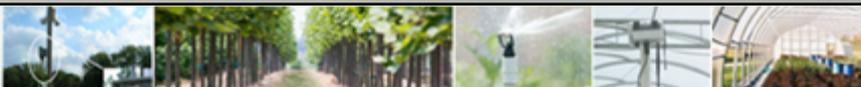


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Smart Farms



SCRI-MINDS—Managing Irrigation and Nutrition via Distributed Sensing

saving water increasing efficiency reducing environmental impacts



United States
Department of
Agriculture

National Institute
of Food
and Agriculture

USDA-NIFA-SCRI Award no. 2009-51181-05768

Our New Tools and Methods

1. Sensor Networks – ground and cloud-based systems
2. “Our Toolbox”
3. Software Development – Translating Information into Decisions
 - *Automated Irrigation Control*
 - *Model Integration*
 - *Alert Capabilities*
4. Economic Impacts – Multiple and Synergistic
5. A Case-study in Risk Management – Frost monitoring

The Process

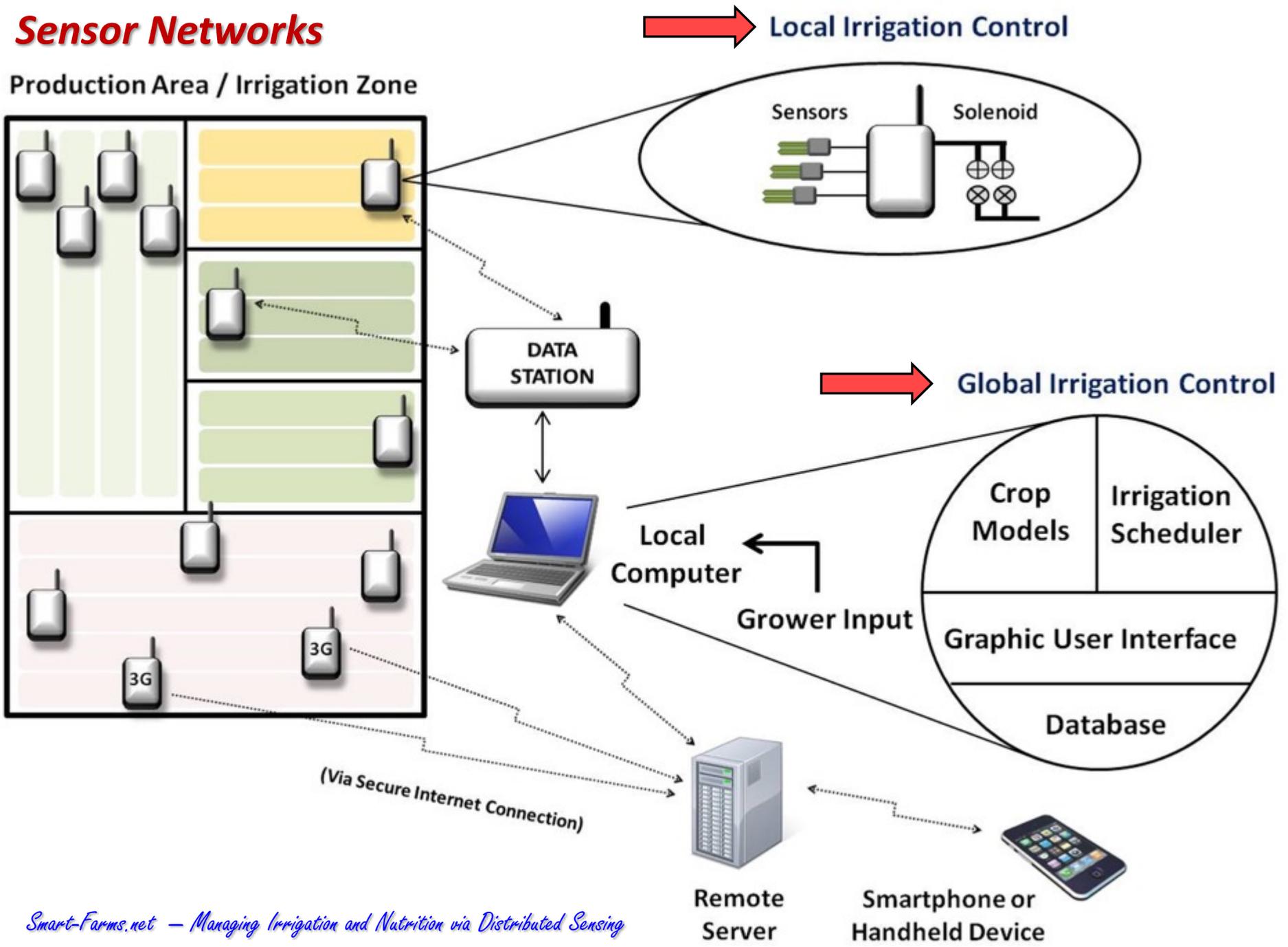
Data → Information → Knowledge → Action

The System

Sensors → Software → 'Analyst' → Decision-Maker



Sensor Networks



Radio Dataloggers



Monitoring
Node



Control
Node

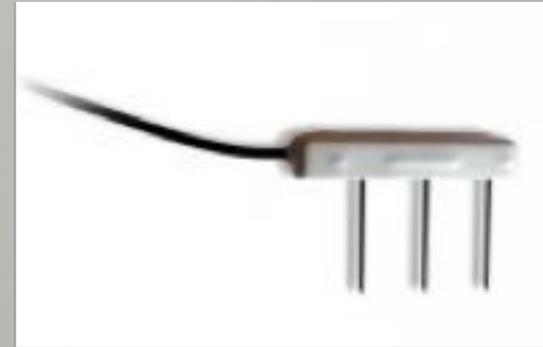


Cellular (3G)
Monitoring Node

Soil Moisture, EC Sensors



Various soil moisture sensors



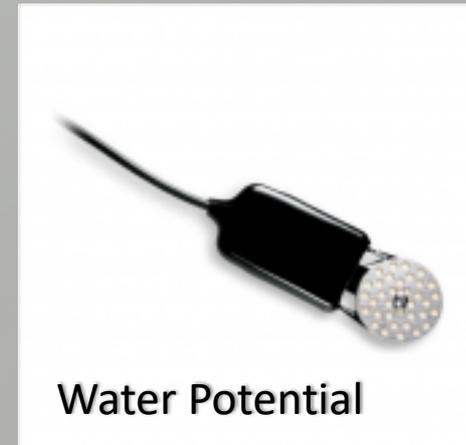
GS3: EC, soil moisture,
soil temperature



Line pressure



In-line/Tank EC



Water Potential

Environmental Sensors



Photosynthetic
and Total radiation



Wind speed
and direction



Precipitation



temperature, RH
and VPD



Sonic anemometer



Leaf wetness, Dew and Ice

Automated Control Capability

- Developed an advanced node, capable of controlling irrigation and reading multiple sensors
- Data is used by growers in real-time to make decisions and monitor crop/field conditions
- Plant irrigation can be determined automatically based on set-points or using plant water use models
- Sensor data and irrigation control can be accessed remotely
- System is fault-tolerant and reliable



PLANTPOINT
Component Specifications

For More Information
PLANTPOINT@CSG.COM
(866) 832-2716

MONITOR NODE	CONTROL NODE	SOFTWARE
<p>W5DC</p> <p>5 sensor ports</p> <p>Supports a variety of Onsen Sensors</p> <ul style="list-style-type: none"> Automatic water control 50' water potential Electrical conductivity Temperature Flow rates <p>800 MHz ISM license-free Radio Technology</p> <ul style="list-style-type: none"> 2.0 mile communication range with Gateway 800 MHz 400 license-free radio technology 200 meters (65') <p>Configurable through SmartBase</p> <ul style="list-style-type: none"> No manual configuration required <p>Powered by 5 AA batteries</p>	<p>W5DC-DC or W5DC-DC</p> <p>2 sensor ports</p> <ul style="list-style-type: none"> For flow meters, electrical conductivity, etc. <p>4 relay ports for valve control</p> <ul style="list-style-type: none"> Basic controller is built (W5DC-DC) and DC solenoid valves (DC24-DC) Integration or gateway control of relay ports <p>Factory time-based watering schedule</p> <p>800 MHz ISM license-free Radio Technology</p> <ul style="list-style-type: none"> 2.0 mile communication range with Gateway 800 MHz 400 license-free radio technology 200 meters (65') <p>Configurable through SmartBase</p> <ul style="list-style-type: none"> No manual configuration required <p>Powered by 5 AA batteries with 24V AC charger (DC24-DC) or solar charger (DC24-DC)</p>	<p>Simple intuitive graphical user interface optimized for commercial users</p> <p>Dashboards with "At-A-Glance" data summary and alerts</p> <p>Set point control using multiple variables</p> <ul style="list-style-type: none"> Automatic water control 50' water potential Electrical conductivity Flow rate/sensor light <p>Allows multiple (dual) control periods per device</p> <p>Irrigation duration support based on user needs, etc.</p> <p>Web interface for PCs, smartphones, and tablets with on-site and remote access</p>
GATEWAY	SMARTBASE	
<p>Links Monitoring and Control Nodes with SmartBase & local area network</p> <p>100' water wheel communication range with SmartBase</p> <ul style="list-style-type: none"> 800 MHz wireless <p>No configuration necessary</p> <ul style="list-style-type: none"> Auto-configure <p>Power and communication over one cable</p> <p>AC</p>	<p>Industrial computer with simple display running PlantPoint software</p> <ul style="list-style-type: none"> No wiring ports and wide temperature range tolerance <p>Factory watchdog functionality with auto reset</p> <ul style="list-style-type: none"> WiFi enabled for remote access and troubleshooting 	

Field studies with the PlantPoint system deployed in operational greenhouses and nurseries have shown, on average, a 50% reduction in applied water, a 20% reduction in nitrogen used, reduced disease losses, and lower production times. For more information on these studies, please visit BIOGROW.COM/OPERATING/PLANTPOINT

Kohanbash, Kantor, Martin and Crawford, 2013
HortTechnology 23: 725-734

SensorWeb Micro-Pulse Irrigation Scheduling Capability

OptiRiego Sensorweb

Feb 22 2016 22:09 CET • 8:10 Sunrise 19:12

Mayim Sensorweb

Dashboard
Data View
Charts
Irrigation
Alerts
Data Export

Select Irrigation Node/Group: Exp_Control | Configure Irrigation Groups

Select Irrigation Control Source: Sensors on the Node | Low Setpoint (0-55%VWC): 18.96 | Pulse Type: Micropulse 240 | **Edit**

Select which moisture sensor ports to use for control (selected sensors must be the same type and will be averaged together):
 Port 1 Port 2 Port 3 Port 4 Port 5

Click on start and end point to create (or delete) schedule below [View All Schedules](#)

gpm 10am 11am 12pm 1pm 2pm 3pm 4pm

submit

Send Manual Irrigation Command

Name	Pulse Duration	Time Between Pulses	Number of Pulse Cycles	Total Time of Event
Standard Single Pulse	300	0	1	300
Cyclic MicroPulse	30	30	6	300
Standard Double Pulse	25	150	2	300
Micropulse 30	30	270	1	270
Micropulse 60	60	240	1	240
Micropulse 90	90	210	1	210
Micropulse 120	120	180	1	180
Double Micropulse 60	60	90	2	300
UNKNOWN TYPE	10	290	1	280
Micropulse 240	240	60	1	300

Name: Micropulse 240

Pulse Duration: 240

Irrigation On: [Graph showing pulse duration]

Irrigation Off: [Graph showing pulse duration]

Time Between Pulses: 60

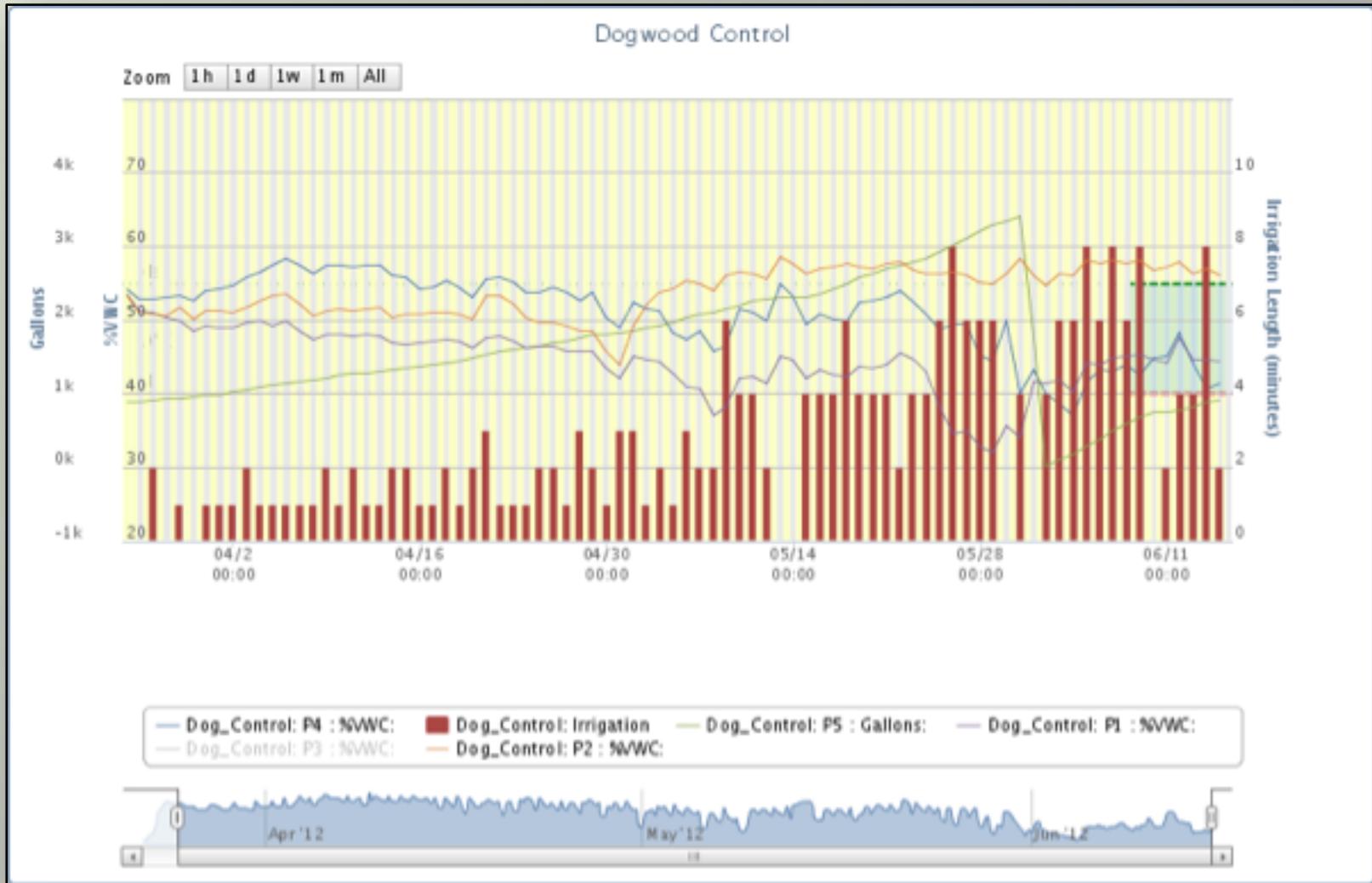
Number of Pulses: 1

Update current relay pulse type | Save as new relay pulse type | Delete current relay pulse type

Add Schedule event

- Sensor-based irrigation control scheduled for 15 minutes every hour
- Within each 15 minute period, able to irrigate up to three, 4-minute pulses (i.e. 240s on, 60s off)
- *Only irrigates* if the minimum soil VWC is reached (currently set at 19% VWC)

Sensor-Controlled Irrigation Scheduling



Irrigation Efficiency – Water Savings

Irrigation Water Applied: March – Nov, 2012 (*Cornus florida*)

Irrigation Method	Total Water Applied (Liters / Row)	Average Water Application (L / Tree /Day)	Av. Efficiency (Timed vs. Control)	Water Savings (Control vs. Timed)
Grower: Timed, Cyclic	109,794	3.49	0.371	2.69
Sensor: Set-point Control	40,769	1.30		

Irrigation water applications reduced between 40 and 70% depending upon species, site-specific variables and time of year

Irrigation Efficiency – Return on Investment

Table 4. Water price comparisons and returns from changing timed cyclic irrigation into sensor-controlled irrigation.

Costs and benefits	Water price [per 1000 gal (3.785 m ³)] ^z			
	\$0.17	\$1.00	\$2.00	\$3.00
Benefits	2.7 year ROI		4-month ROI	
Pumping cost savings	\$ 8,137	\$46,944	\$94,189	\$141,283
Management cost savings	\$12,150	\$12,150	\$12,150	\$12,150
Annual savings	\$ 20,288	\$59,094	\$106,339	\$153,433
Costs				
Annualized sensor system cost	\$14,205	\$14,205	\$14,025	\$14,025
Annual maintenance	\$ 1,000	\$1,000	\$1,000	\$ 1,000
Total sensor system cost	\$15,205	\$15,205	\$15,025	\$15,025
Annual net savings	\$ 5,263	\$44,069	\$91,313	\$138,408

^zCorresponding water prices = \$55, \$326, \$652, and \$978 per acre-foot; \$1/acre foot = \$8.1071/hectare-meter.

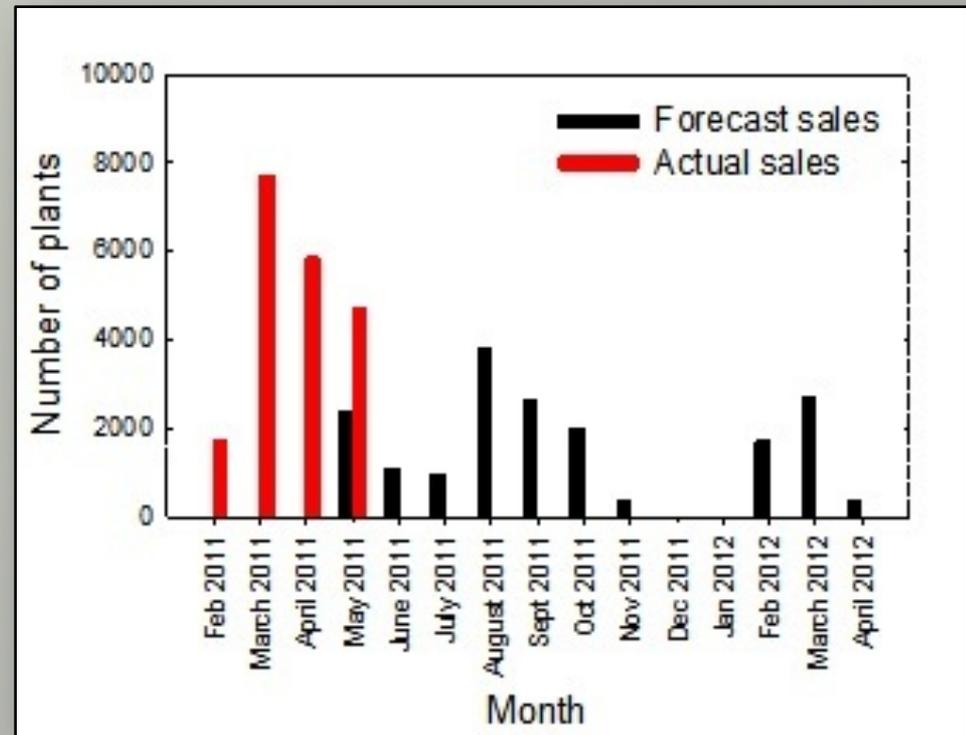
Fungal Disease Management



Gardenia 'radicans' - high shrinkage due to crop death/unmarketable final product.

Reduction in Production Times, Net Benefits

- ✓ 14-month production cycle collapsed to 8-month
- ✓ 30% loss to Disease reduced to virtually zero
- ✓ Economic Gain = \$1.06 / ft²
(total net revenue = \$20,700 for crop)
- ✓ ROI < 3 months for \$6,000 network



Economic Analysis of Cut-flower Production

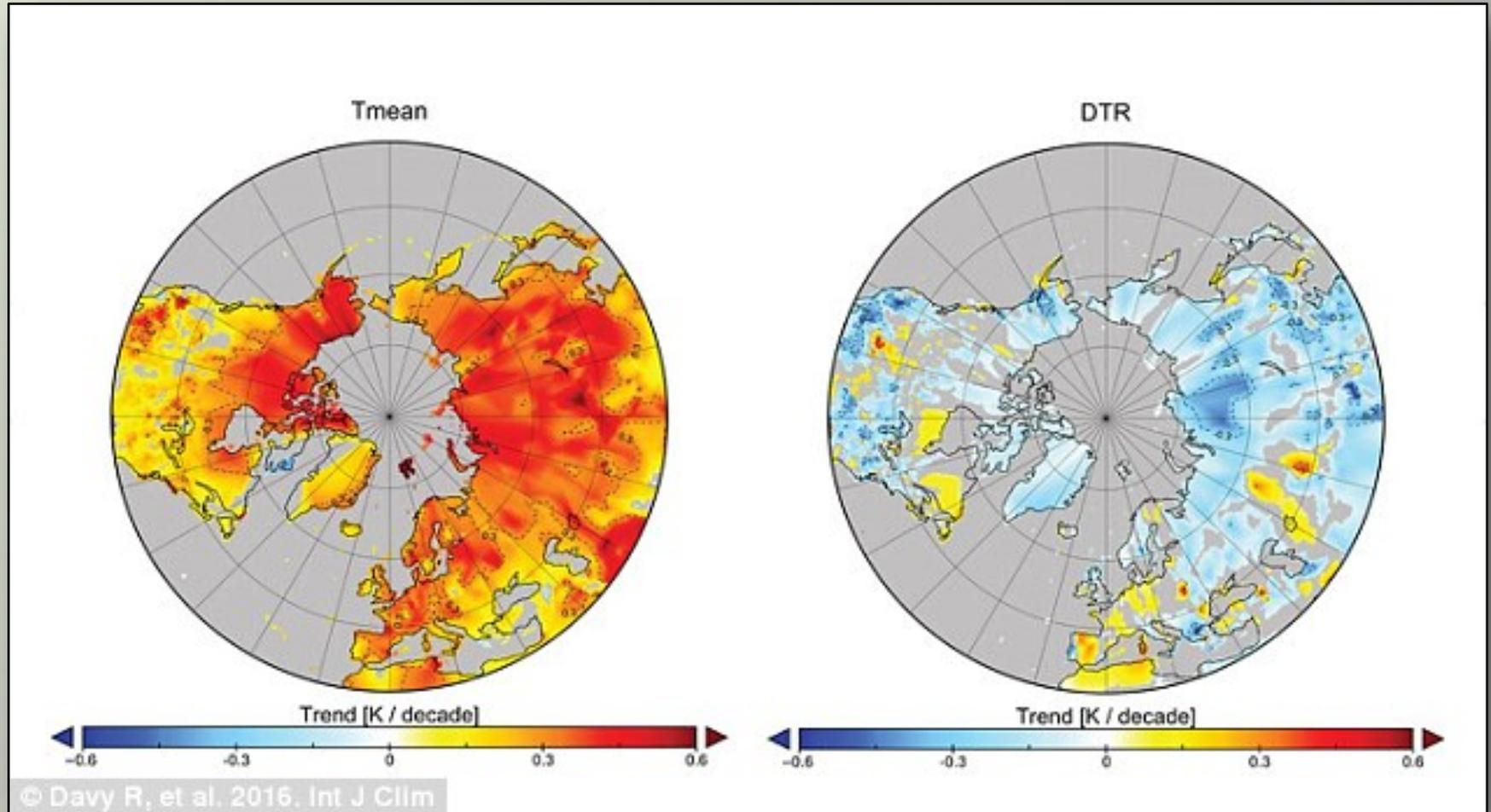
Pre-Sensor: (2007 – 2009)

Post-Sensor: (2010 – 2012)

	2007 -2009	2010- 2012	Difference	Change
Crops/ year	37	38	1	1 %
Stems/ year	106,308	139,382	33,074	31 %
Price/ stem	\$ 0.59	\$ 0.62	\$ 0.03	5 %
Labor costs	\$ 15,905	\$ 17,893	\$ 1,988	12 %
Electricity	\$ 4,109	\$2,923	\$ 1,186	-29 %
Sensor system	\$ 0	\$7,147	\$ 7,147	---
Revenue	\$63,094	\$ 85,679	22,585	36 %
Profit	\$43,080	\$57,716	\$14,636	34 %

Payback period on upfront costs: <16 months

The Planetary Boundary Layer



The Planetary Boundary Layer

INTERNATIONAL
JOURNAL OF CLIMATOLOGY

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RESEARCH ARTICLE

Diurnal asymmetry to the observed global warming

Richard Davy , Igor Esau, Alexander Chernokulsky, Stephen Outten, Sergej Zilitinkevich

First published: 24 February 2016 [Full publication history](#)

DOI: 10.1002/joc.4688 [View/save citation](#)

Cited by: 3 articles  [Citation tools](#)

 score 73

[Funding Information](#)



[View issue TOC](#)
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January 2017
Pages 79-93

ABSTRACT

The observed warming of the surface air temperature (SAT) over the last 50 years has not been homogenous. There are strong differences in the temperature changes both geographically and on different time frames. Here, we review the observed diurnal asymmetry in the global warming trend: the night-time temperatures have increased more rapidly than day-time temperatures. Several explanations for this asymmetric warming have been offered in the literature. These generally relate differences in the temperature trends to regionalized feedback effects, such as changes to cloud cover, precipitation or soil moisture. Here, we discuss a complementary mechanism through which the planetary boundary layer (PBL) modulates the SAT response to changes in the surface energy balance. This reciprocal relationship between

The Planetary Boundary Layer

PLANETARY BOUNDARY LAYER

According to climatologists, the reason for the rapid increase is a band of air close the ground, called the planetary boundary layer (PBL).

This thin layer of the Earth's atmosphere is distinct from the upper layers and changes in thickness over the course of the day-night cycle.

At night the solar radiation absorbed by the surface over the course of the day is released into space.

The researchers explain that as more carbon dioxide has been added to the atmosphere from man-made activities, such as burning fossil fuels, this has meant less heat escapes from the atmosphere at night, and the warmer atmosphere heats the thin PBL below.

Because the layer is so thin at night, the warming effect is much more pronounced, adding extra energy to the climate system

Agricultural Implications of Increased Night Temperatures

1. Increased respiration rates
 - Decrease in yield
 - Decrease in food quality
2. Disruptions in pollination, fruit set
3. Increase in soil temperatures, microbial respiration rates, decrease in organic matter content
4. Increase in relative humidity, fungal disease
5. Increased weed pressure
6. Increased number of pest life cycles

On-farm Weather Station

DS-2 Sonic Anemometer

Wind speed and direction

VP-4

Temp, RH, VPD,
Barometric Pressure

Pyranometer

Solar Radiation

QSO-S PAR

PAR (visible light)

ECRN-100 Rain gauge

Precipitation

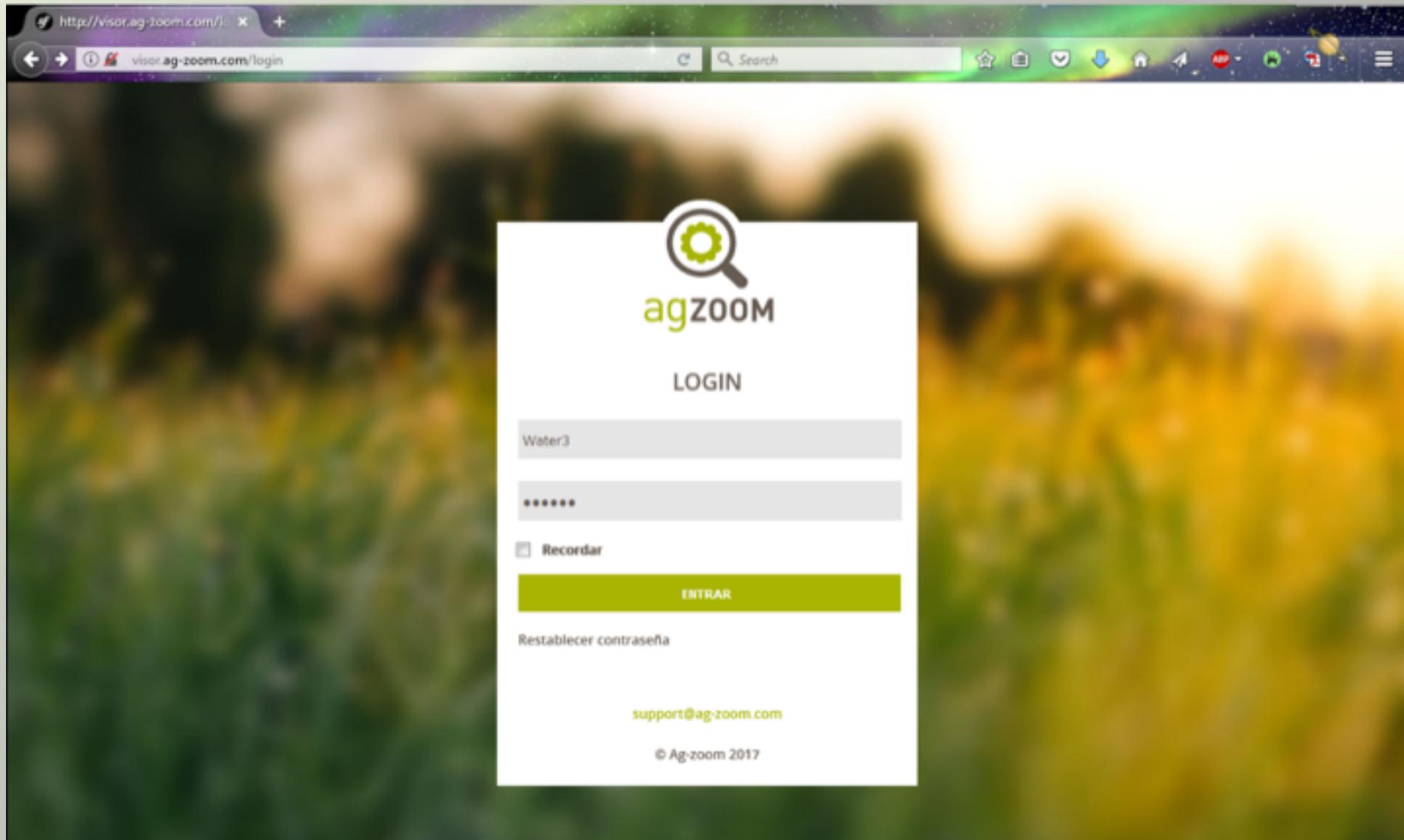
**Em50G “cloud –based”
data logger**



3G Telemetry



Cloud Software Capabilities: AgZoom



The image shows a web browser window displaying the login page for AgZoom. The browser's address bar shows the URL `http://visor.ag-zoom.com/` and the page title is `visor.ag-zoom.com/login`. The login form is centered on the page and features the AgZoom logo at the top, which consists of a magnifying glass over a gear icon. Below the logo, the word "agZOOM" is displayed in a green and black font, followed by the word "LOGIN" in a simple black font. The form includes a text input field containing "Water3", a password input field with six dots, and a checkbox labeled "Recordar". A prominent green button labeled "ENTRAR" is positioned below the form. At the bottom of the form, there is a link for "Restablecer contraseña", the email address "support@ag-zoom.com", and the copyright notice "© Ag-zoom 2017".

http://visor.ag-zoom.com/

visor.ag-zoom.com/login


agZOOM

LOGIN

Water3

Recordar

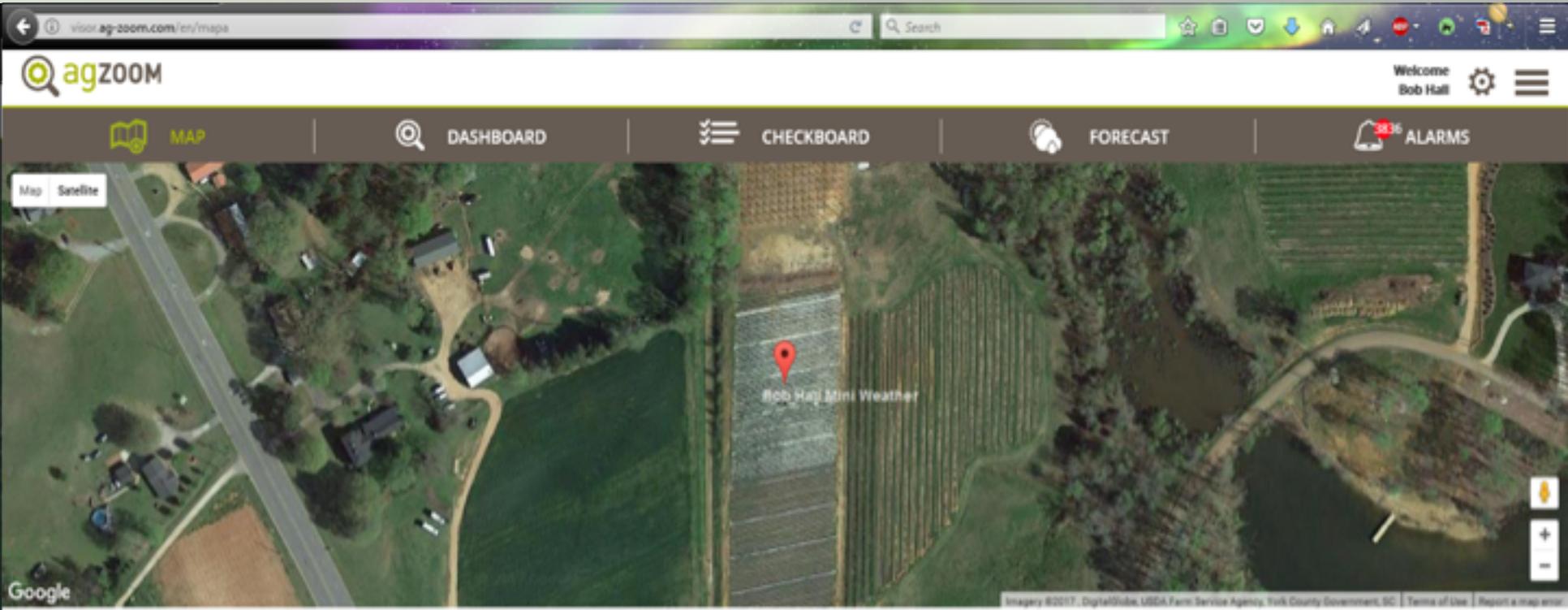
ENTRAR

[Restablecer contraseña](#)

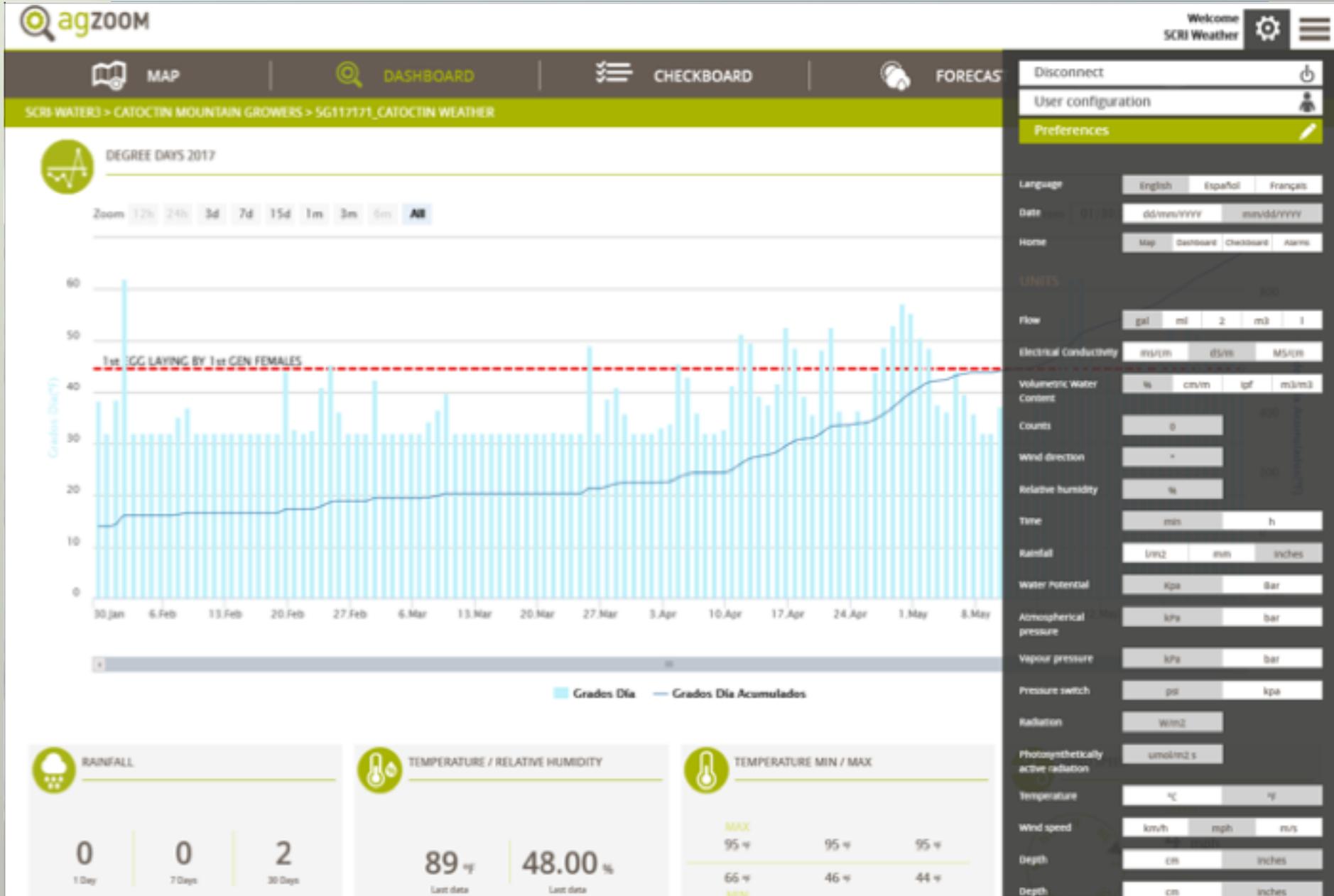
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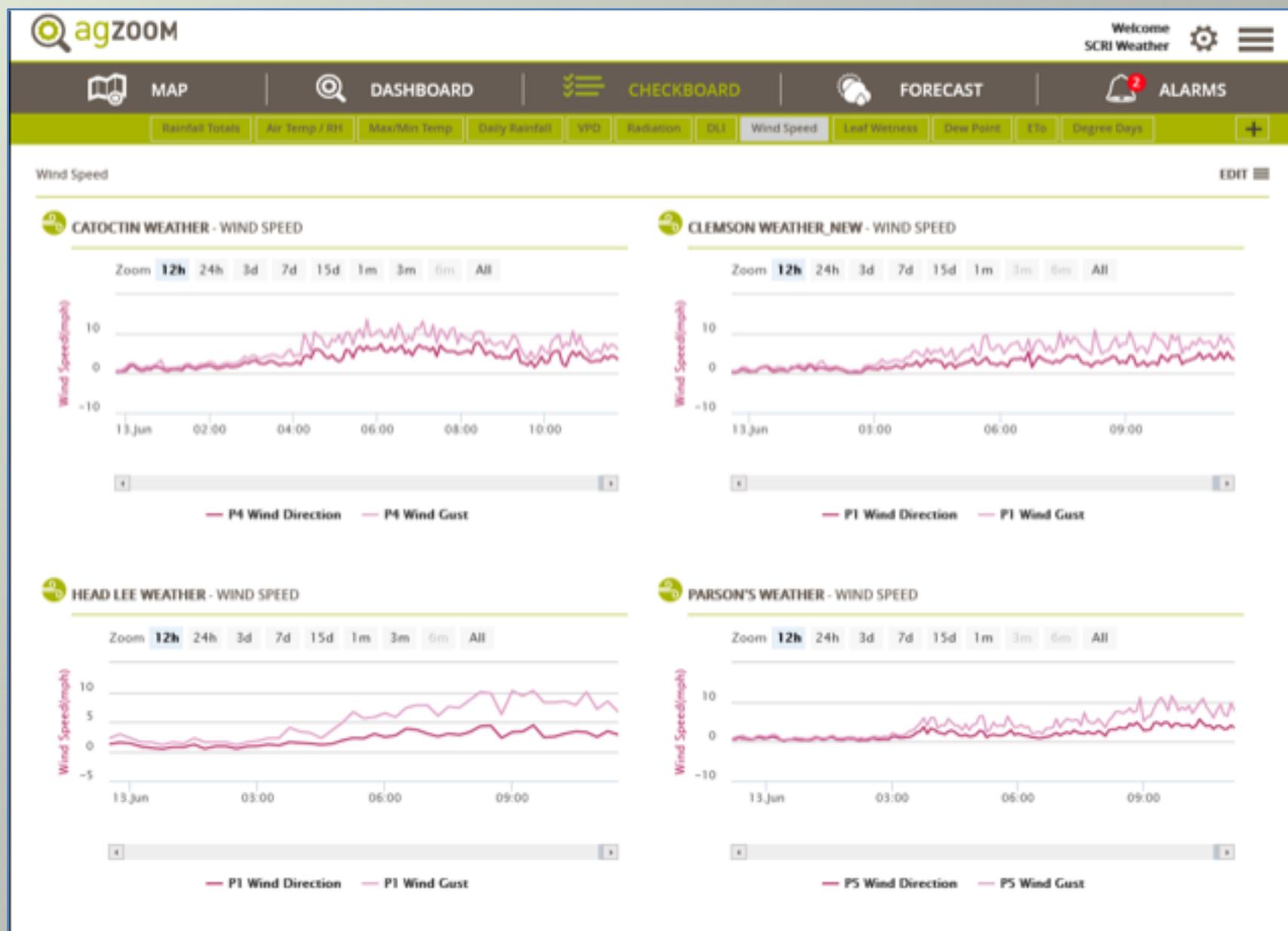
Geolocation of Cloud Dataloggers



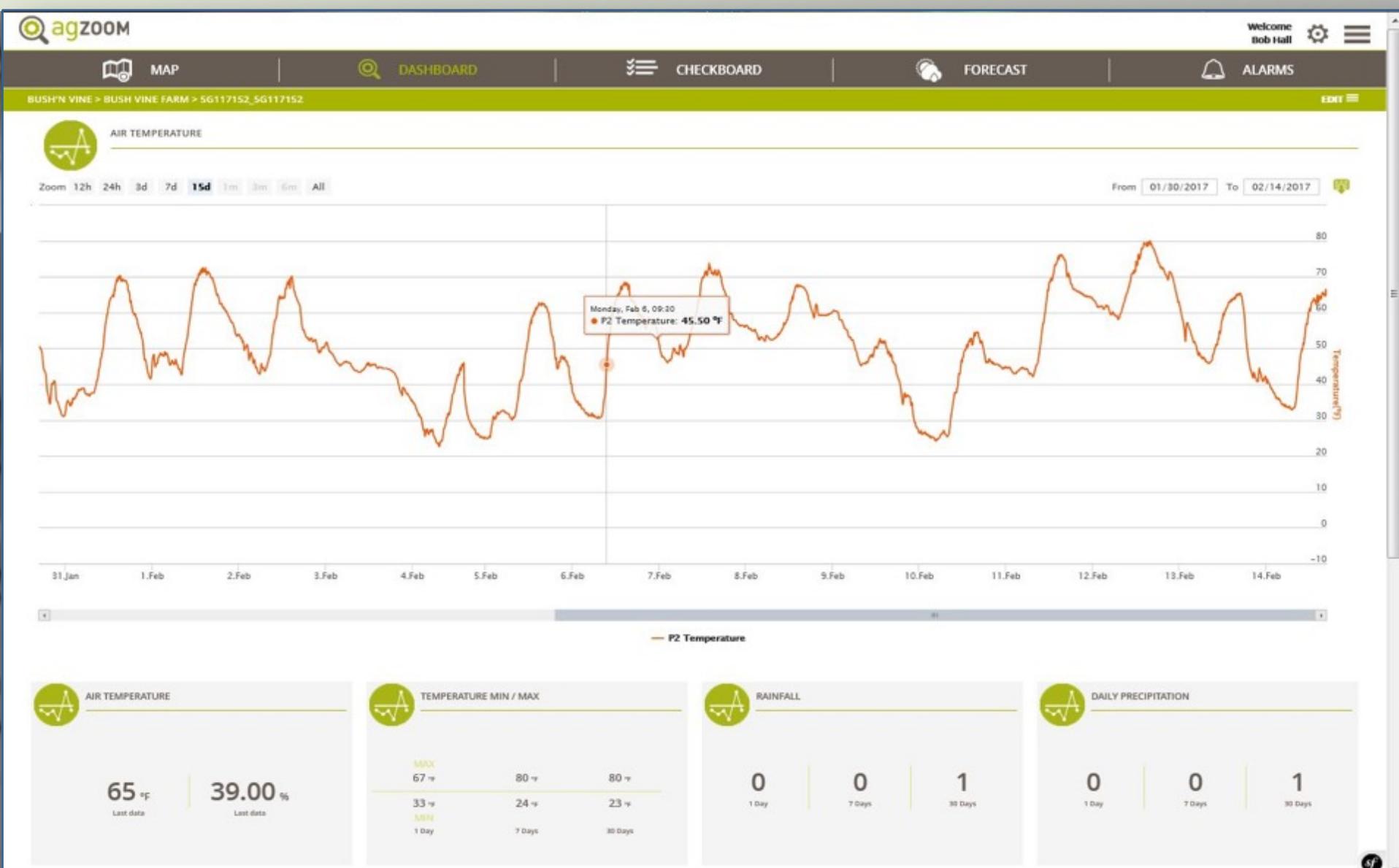
Dashboard – Single Node Data



Checkbox – Aggregate Data



AgZoom Software



Geolocated 7-Day Weather Forecast

The screenshot displays the agZOOM weather application interface. At the top, the agZOOM logo is on the left, and 'Welcome SCRI Weather' with settings and menu icons is on the right. A navigation bar below contains icons for MAP, DASHBOARD, CHECKBOARD, FORECAST (highlighted), and ALARMS (with a notification badge). The main content area is titled 'Weather Bush 'n Vine Farm' with coordinates 47.56°N 7.58°E and a timestamp of 247m ago. A 7-day forecast is shown with icons and temperature ranges for each day. Below this, there are sections for 'Current weather', 'Webcams', 'Metagrams', 'Multimodel', and 'Detail'. A 'Special' section promotes smartphone apps. The 'Active / Climate' section shows a detailed hourly forecast for Wednesday, including temperature, wind, and precipitation data. At the bottom, there are UV index indicators, moon phase, and technical weather data like water temperature, pressure, and time zone.

Forecast

Day	Wed	Thu	Fri	Sat	Sun	Mon	Tue
Forecast	☁️	☁️	☁️	☀️	☀️	☀️	☀️
7-day weather	81°F	87°F	74°F	74°F	83°F	84°F	83°F
14-day weather	60°F	62°F	61°F	55°F	57°F	60°F	63°F
Current weather	→ 3 mph	→ 3 mph	→ 10 mph	→ 6 mph	→ 7 mph	→ 8 mph	→ 7 mph
Webcams	↑ 4h	↑ 2h	↑ 2h	↑ 12h	↑ 12h	↑ 10h	↑ 7h

Wednesday

Time	02 ⁰⁰	05 ⁰⁰	08 ⁰⁰	11 ⁰⁰	14 ⁰⁰	17 ⁰⁰	20 ⁰⁰	23 ⁰⁰
Temperature (°F)	63°	66°	62°	72°	79°	86°	78°	69°
Temperature felt (°F)	63°	66°	61°	73°	81°	81°	79°	71°
Wind direction	↙ SSW	↙ SW	↙ S	↙ NE	↙ N	↙ SE	↙ E	↙ E
Wind speed (mph)	2-6	2-7	4	4-8	5-9	5-7	4-6	4-5
Precipitation (in/2h)	-	-	-	-	-	-	-	-
Precipitation probability	0%	0%	0%	10%	0%	20%	10%	10%
Precipitation hourly								
rainPOI								

Water temperature Rhein: 20°C
 Pressure: 1015 hpa
 Timezone: CEST
 Domain: NEM54
 Last model run: 2017-06-13 21:31

AgZoom – Alert Capability



Welcome
Bob Hall  



Alarms **Alarms Configuration** SMS

Date	Customer	Farm	Device	Alarm	Variable	Value	Current data	
16-03-2017 14:25:50	Bush'n Vine	Bush Vine Farm	SG117152	Row Cover Temperature Alert	Temperature	< 36 °F	21.00 °F	
Date	Value	Message						
16-03-2017 14:25:50	35.78 °F	35.78 °F < 36 °F						
16-03-2017 14:05:51	35.24 °F	35.24 °F < 36 °F						
16-03-2017 13:55:34	34.52 °F	34.52 °F < 36 °F						
16-03-2017 13:36:07	33.98 °F	33.98 °F < 36 °F						
16-03-2017 13:25:54	33.80 °F	33.80 °F < 36 °F						
16-03-2017 13:05:42	33.80 °F	33.80 °F < 36 °F						
16-03-2017 12:55:36	33.62 °F	33.62 °F < 36 °F						
16-03-2017 12:36:01	33.98 °F	33.98 °F < 36 °F						
16-03-2017 12:21:07	34.16 °F	34.16 °F < 36 °F						
16-03-2017 12:05:43	34.52 °F	34.52 °F < 36 °F						
16-03-2017 11:55:40	34.70 °F	34.70 °F < 36 °F						
16-03-2017 11:35:54	34.88 °F	34.88 °F < 36 °F						
16-03-2017 11:25:39	35.06 °F	35.06 °F < 36 °F						
08-04-2017 14:36:16	Bush'n Vine	Bush Vine Farm	SG117152	Bush n Vine Frost Alert	Temperature	<= 36 °F	20.80 °F	



support@ag.zoom.com

Frost Monitoring

- Current frost prediction tool - Sky-Bit (Satellite data)
- Air temperature is not a reliable predictor of frost events
- Canopy temperature should be measured
- Radiative frost: $CT \ll AT$ on clear and calm nights



- 2 precision thermistors
- Mimic plant leaf and flower bud
- Measurement Range: -50 to 70 °C
- Accuracy: ± 0.1 to ± 0.4 °C

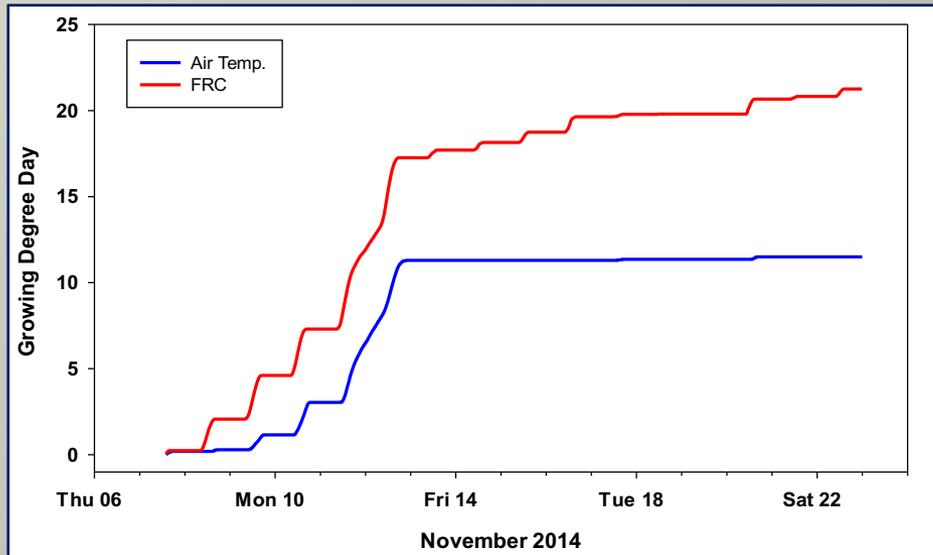
Apogee SF-110 Radiation Frost Sensor

Radiative Frost Sensor



Flower bud and leaf thermistors (indicated with red arrows) on the SF-110 radiation frost sensor deployed within the plant canopy at Shlagel Farms

Floating Row Cover Use



Growing degree day (GDD) units recorded below and above floating row cover

Frost Events South Carolina – March 14-16, 2017



Welcome Bob Hall  

 MAP

 DASHBOARD

 CHECKBOARD

 FORECAST

 3836 ALARMS

BUSH'N VINE > BUSH VINE FARM > 5G117152_BOB HALL MINI WEATHER

EDIT 



CROWN (ROW COVER) AIR TEMPERATURE



SUMMARY DATA

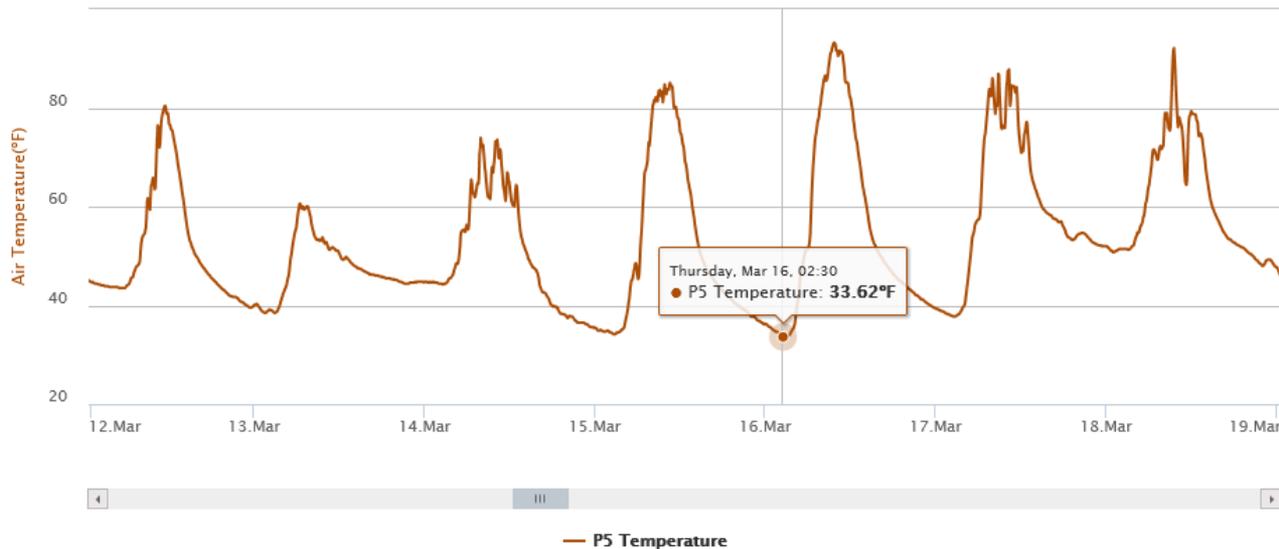
Zoom **12h** 24h 3d **7d** 15d 1m 3m 6m All

From To



P5 Temperature

Average	Min	Max
53.58	33.62	93.20



TEMPERATURE MIN / MAX

MAX		
89 °F	89 °F	92 °F
65 °F	58 °F	49 °F
MIN		
1 Day	7 Days	30 Days



RAINFALL

0	0	7
1 Day	7 Days	30 Days



DAILY PRECIPITATION

0	0	7
1 Day	7 Days	30 Days



PHOTOSYNTHETICALLY ACTIVE RADIATION (PAR)

44 umol/m² s
Last data

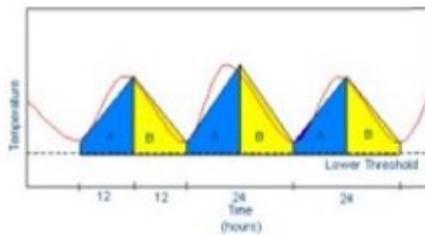
Predictive Tools for IPM, Disease Management

Agricultural Risk Management

Precision Farming is more than just GPS controlled harvesters. It also helps keeping track of pathogen development, optimize treatments to hit a disease dead on, warn of frost, and to produce as environmentally friendly as possible.

Growing Degree Days, Heat Units

The growth and development of plants, insects, and many other invertebrate organisms is largely dependent on temperature.



In other words, a constant amount of thermal energy is required for the growth and development of many organisms, but the time period over which that thermal energy is accumulated can vary. Many organisms slow or stop their growth and development when temperatures are above or below threshold levels. The accumulation of thermal energy over time is known as degree-days or heat units. Degree-days and other heat unit measurements have been used for determination of planting dates, prediction of harvest dates, and selection of appropriate crop varieties.

Adcon's Heat Unit extension, which is part of our data visualization and distribution software addVANTAGE Pro, includes the most commonly used methods for calculating heat units. The user is able to create templates based on information found in published models. The templates can include the method of heat unit calculation and thresholds levels for alarms - crucial for precise management decisions.

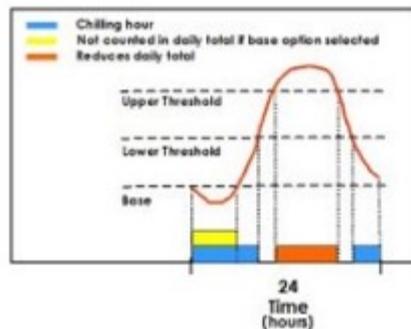
Calculation methods

Cutoff method

Chilling Hours

User friendly model template

Download information

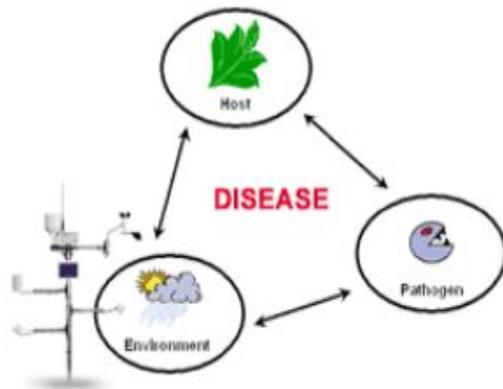


Chilling units values are used to predict several management factors. Fruit growers are the primary users of chilling hours. Decisions such as varietal selection, pruning, and other management factors related to potential yields can be aided by chilling hour calculations.

Agricultural Risk Management

Precision Farming is more than just GPS controlled harvesters. It also helps keeping track of pathogen development, optimize treatments to hit a disease dead on, warn of frost, and to produce as environmentally friendly as possible.

Decision Support



Plant disease initiation and development is a function of the interaction of several factors. That interaction is often referred to as the "Disease Triangle". Adcon Telemetry's plant disease risk assessments are based on the disease triangle. Adcon hardware (weather stations) in the field collects environmental data and delivers it to the receiver where it is available for processing by the addVANTAGE Pro software. The result is an up to date assessment of disease risk.

Treatment
Recommendations

On-Time
Treatments

Model Validation

Make better
decision in many
areas!

Download
information

- 📄 Grape Bunch Rot
- 📄 Grape Downy Mildew
- 📄 Grape Downy Mildew V2.0
- 📄 Grape Powdery Mildew
- 📄 Heat Units
- 📄 Hops Downy Mildew
- 📄 Hops Powdery Mildew
- 📄 Lettuce Downy Mildew
- 📄 Main
- 📄 Maryblyt

Adcon Telemetry cooperates with leading academic, public sector, and industry researchers to validate the models incorporated into the addVANTAGE program. Adcon works actively as a partner in model validation to ensure that the models offered to our clients work well with Adcon hardware and software as well as being valid for specific areas and crops.

The screen shot to the left shows a short extract of the list of models that are available for addVANTAGE Pro, with more being added all the time.

Impacts

Synergistic Capabilities:

1. Precision Water and Nutrient Management
2. Timeliness of Decisions; Opportunity Costs
3. Intelligent Alerts
4. Better Predictive Capabilities

Can translate into Multiple Benefits:

1. Reduced Risk and Crop Losses
2. Reduction in Production Times
3. Increased Crop Yield and Quality

Project Information at <http://smart-farms.net>

Smart Farms Home | Smart Farms - Mozilla Firefox

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smart-farms.net

Smart Farms Home | Smart Farms

Smart Farms Knowledge Center

Smart Farms

SCRIP-MINDS—Managing Irrigation and Nutrition via Distributed Sensing

saving water increasing efficiency reducing environmental impacts

HOME APPROACH ENVIRONMENTS R&D TEAMS RESEARCH SITES PARTNERS ECONOMICS PUBLICATIONS IMPACTS

Smart Farms Home

- Network Development
- Direct Sensing Approach
- Modeling Approach
- Advisory Panel

Smart Farms Home

Our project is all about saving water, increasing efficiency and reducing the environmental impacts of ornamental plant production practices! We are using wireless sensor networks and environmental modeling to more accurately predict and apply irrigation water in nursery and greenhouse operations, and monitor green roofs for stormwater mitigation.

Our goal is to provide growers with the ability to precisely monitor and control applications of water and nutrients to plants in these production settings, based upon daily plant requirements.

Our vision is to provide the nursery and greenhouse industries with cost-effective equipment and strategies that can be used to reduce the volume and cost of inputs, increase profitability, reduce the environmental impacts of nursery and greenhouse production and encourage sustainable practices in the United States and beyond.

The purpose of this website is to provide you with an overview of our project and information about the research and development of an advanced environmental monitoring and irrigation system. We are actively collaborating with a number of commercial growers using their production areas as test environments. These collaborations will help us learn to best implement this new technology to minimize cost and maximize efficiency.

```
graph TD
    subgraph ProductionArea [Production Area / Irrigation Zone]
        S1[Sensor]
        S2[Sensor]
        S3[Sensor]
        S4[Sensor]
        S5[Sensor]
        S6[Sensor]
        S7[Sensor]
        S8[Sensor]
    end
    subgraph LocalIrrigationControl [Local Irrigation Control]
        Sol[Solenoid]
        Sol2[Solenoid]
    end
    subgraph LocalComputer [Local Computer]
        DS[Data Station]
        LC[Local Computer]
    end
    subgraph GlobalIrrigationControl [Global Irrigation Control]
        CM[Crop Models]
        IS[Irrigation Scheduler]
        GUI[Graphic User Interface]
        DB[(Database)]
    end
    subgraph RemoteServer [Remote Server]
        RS[Remote Server]
    end
    subgraph Smartphone [Smartphone or Handheld Device]
        SHD[Smartphone or Handheld Device]
    end

    S1 --> DS
    S2 --> DS
    S3 --> DS
    S4 --> DS
    S5 --> DS
    S6 --> DS
    S7 --> DS
    S8 --> DS
    DS --> LC
    LC --> Sol
    LC --> Sol2
    LC --> RS
    RS --> SHD
    SHD --> RS
    RS --> CM
    RS --> IS
    RS --> GUI
    RS --> DB
    RS --> SHD
    SHD --> RS
```